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RESEARCH MEMORANDUM

SOUND MEASUREMENTS FOR FIVE SHROUDED PROPELLERS

AT STATIC CONDITIONS

By Harvey H. Hubbard

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

Sound-pressure measurements are reported for five propeller-shroud combinations and are compared with those for an unshrouded propeller operating at approximately the same tip speed and power coefficient.

The maximum total sound pressure produced by a two-blade shrouded propeller is found to vary approximately from half to twice as much as that for a two-blade unshrouded propeller depending on whether the flow at the shroud surface is unseparated or separated, respectively. During conditions of unseparated flow the higher harmonics of rotational sound are greatly attenuated, the vortex noise produced is at a minimum, and the resulting sound is predominantly of low frequency. For the separated flow condition, all rotational-sound frequencies are reinforced, the vortex noise is much greater, and an unpleasant high-frequency sound results.

As is the case with unshrouded propellers, an increased number of blades and a reduction in tip speed tend to reduce the sound pressures.

Shroud chord length is found not to be critical except insofar as the aerodynamic considerations are affected. Tip clearances of less than 1 percent of the diameter are found to be satisfactory from a sound standpoint. In general, results indicate that the best shroud unit from aerodynamic considerations will also produce the minimum sound.

INTRODUCTION

The possibility of decreasing the sound and increasing the thrust of a propeller by means of a shroud has been discussed in reference 1. An analytical investigation and a series of wind-tunnel tests of a shrouded propeller are included in reference 2.

Recent static tests of a shrouded-propeller unit (reference 3) have indicated that approximately twice as much static thrust was obtained at a given power coefficient as with an unshrouded propeller, chiefly because the unshrouded propeller was stalled while the shrouded propeller was unstalled. During these tests it was observed that at times the shroud unit ran quietly and at other times it was very noisy. During noisy operation the flow was observed to be separated from the inner shroud surface at the leading edge and during quiet operation the flow was unseparated.

Since the shrouded-propeller unit shows some promise aerodynamically for application to personal-owner-type aircraft and because few, if any, sound measurements have been reported on shrouded propellers, it seemed desirable to investigate experimentally the sound produced by them.

Static tests were made for a two-blade propeller operating in four different shrouds and, in addition, a limited number of tests were made with a five-blade shroud unit. The sound data obtained are compared with the sound from an unshrouded propeller operating at the same tip speed and power coefficients.

SYMBOLS AND DEFINITIONS

R	propeller tip radius, feet
r	station radius, feet
b	section chord, feet
D	propeller diameter, feet
h	section thickness, feet
T	thrust developed by shroud, pounds
P_H	horsepower
p	sound pressure, dynes per square centimeter
N	propeller rotational speed, rpm
M_t	tip Mach number
Z	tip clearance, feet
m	order of harmonic

B	number of blades
s	distance, feet
θ	angle measured from axis of rotation, degrees (0° in front)
β	blade angle, degrees

Subscript:

0.75	measured at $r = 0.75R$

Rotational noise — The rotational noise of a propeller is the noise due to the steady aerodynamic forces on the blades. The frequencies are integral multiples of the fundamental frequency of blade passage (rotational frequency multiplied by the number of blades), and the pressures are a maximum slightly behind the plane of rotation.

Vortex noise — The vortex noise is due to the unsteady forces on the propeller blade. The pressures are a maximum on the axis of rotation, and the frequencies are random.

APPARATUS AND METHODS

Static tests were conducted for the measurement and analyses of the sound emission of five different propeller-shroud combinations. Tests were made for a two-blade propeller with the four different shrouds described in tables I to IV, for a two-blade unshrouded propeller, and for one five-blade shrouded configuration. Most of the tests were made with the shroud unit of figure 1 which consists of shroud B (see table II) and the two-blade propeller because this combination gave consistent results and allowed the propeller-plane position to be adjusted.

The two-blade, 4-foot-diameter propeller used in the tests was designed for shroud operation at a forward speed of about 120 miles per hour and has Clark Y blade sections. The blade-form curves are given in figure 2(a). This propeller was designed to operate at a speed of 3300 rpm and a blade angle $\beta_{0.75}$ of 21.5° and at these latter conditions in static tests the power absorbed is near the maximum available from the drive motor.

The five-blade, 4-foot-diameter propeller incorporates the same blades as were used for the tests in reference 3, and the blade-form

curves are shown in figure 2(b). This propeller was operated in shroud B at approximately the same tip speed and power coefficient as the two-blade propeller for comparison of results.

The unshrouded two-blade propeller has rounded tips whereas the shrouded propellers have squared tips. In all other respects the unshrouded propeller is identical to the shrouded two-blade propeller.

Flow separation from the inside shroud surface near the nose occurs at low rotational speeds for all shroud-propeller combinations. This flow separation established the lower limit of the speed range for the test. The top speed for continuous operation was limited to approximately a tip Mach number of 0.60 by the power of the drive motor; however, a limited amount of data were taken at a tip Mach number of 0.73.

The test propellers were driven by a 200-horsepower, water-cooled, variable-speed electric motor. Power inputs to the drive motor in all tests were measured directly by means of a wattmeter and these readings were corrected by means of motor-efficiency data to determine the power input to the propeller. The motor was rigidly mounted on an outdoor test stand as shown in figure 1.

The shrouds were designed with a fairly large leading-edge radius, and the sections were set at a -4° angle of attack, as illustrated in figure 3, in the hope that the tendency for the flow to separate at the nose would be lessened for static conditions. Since size and weight, as determined principally by the chord length, are of great importance, shrouds C and D with chord lengths of 9.6 inches, B with 19.2 inches, and A with 28.8 inches were tested to evaluate the effect of chord length on the sound emission. Differences in the airfoil section, leading-edge radius, and so forth, which were introduced in an attempt to help stabilize the flow, were also present in this series of shrouds as indicated in the following paragraph.

Shroud-A ordinates, as given in table I, were obtained by modifying the NACA 4312 airfoil section to increase the nose radius by 50 percent. From the 30-percent-chord station to the trailing edge the ordinates are those of the NACA 4312 section and ahead of the 30-percent station they are greater than the normal NACA 4312 ordinates. The same type of modification, as indicated in tables II and III, was made to the NACA 4315 and NACA 4318 ordinates to obtain the section of shroud B and shroud C, respectively. The leading-edge radius for shroud D was made the same as for shroud B. To accomplish this, the normal leading-edge radius of the NACA 4318 airfoil section was increased by 109 percent as shown in table IV. Shrouds C and D offer a comparison, respectively, between a nearly conventional airfoil with one that has a much larger leading-edge radius than normal.

The shroud units were normally operated with the propeller plane at 40 percent of the chord, measured from the leading edge. At this station, which is at the minimum shroud diameter, the propeller-tip clearance is 3/32 inch. One propeller-shroud combination was operated also with the propeller plane at the 32- and 48-percent stations for comparison. At the 40-percent station the blades were progressively shortened in a series of tests to evaluate the effect of increasing the propeller tip clearance.

Root-mean-square sound pressures were measured by a Massa Laboratories Model GA-1002 sound-pressure-measurement system calibrated to read directly in dynes per square centimeter. The microphone was placed at ground level to insure maximum pickup of all frequencies at a distance of 30 feet from the propeller hub and at various angles θ from the propeller axis of rotation (0° in front of propeller). Pressure amplitudes (rms) of the first four harmonics of the rotational sound were measured with a Hewlitt-Packard harmonic wave analyzer adjusted to a band width of 100 cycles per second. Total sound measurements were also made for each test condition.

No propeller-thrust data were measured; however, pressure measurements on the shroud surfaces, from which shroud thrust was calculated, were recorded by means of a multiple manometer. These pressure data were measured at one section and are assumed to apply all around the shroud periphery.

For these static tests, wind direction was critical in establishing the air flow in the shroud. Cross winds and tail winds generally caused a separation of the air flow on parts of the shroud surface, and head winds generally assisted in establishing unseparated flow. Flow conditions were observed by means of tufts located around the periphery of the shroud on the inside surface near the leading edge.

RESULTS AND DISCUSSION

As observed in earlier shroud tests (reference 3) the sound produced by a shroud unit is found to be influenced by the flow conditions at the shroud surface. In general, the sound produced by a given unit is less when the flow at the shroud surface is unseparated than when it is separated.

Total sound.- Measurements of the total sound pressures as shown in figure 4 give a comparison between the two-blade shrouded and the two-blade unshrouded propeller at the same tip speed and power coefficient. At the angle of maximum sound ($\theta = 120^{\circ}$ approx.) the sound pressures produced vary from approximately one-half as much to twice as

much as the unshrouded propeller, depending on the flow conditions. For the separated-flow condition, the vortex noise, which normally appears strongest on the propeller axis of rotation, is observed to be much increased, and the resulting sound is unpleasant. For the unseparated-flow condition, the vortex noise is apparently less, and the sound produced has a predominant low-frequency content.

An appraisal of the quality of the sound produced at these two flow conditions may be obtained from figure 5. Cathode-ray oscillograph pictures of the sound produced by a shrouded propeller are shown (a) for unseparated flow, and (b) for separated flow on a section of the shroud surface resulting from a cross wind. Both photographs are at the same gain for comparison of amplitudes and the time interval between them is about 1 minute. It is apparent that the contribution of the high frequencies is much greater for the separated-flow condition.

Frequency analysis.- A clearer picture of the frequency content of the total sound pressures represented by the three conditions of figure 4 can be obtained from figure 6. In this figure the relative amplitudes of the first four harmonics of rotational sound of a two-blade shrouded and unshrouded propeller are presented. All data were taken at the same tip speed and power coefficients for comparison. Figure 6 indicates that the maximum rotational-sound amplitudes were not greater for a shrouded propeller than for an unshrouded propeller at the same tip speed and power coefficient. A substantial reduction for all rotational frequencies may be realized, however, if favorable flow conditions exist in the shroud, and the amount of such a reduction depends on the order of the harmonic, the higher harmonics being reduced by the greater amount.

Shroud chord length.- In order to determine the effect of shroud chord length on the total sound, a limited number of tests were made with the same propeller in combination with shrouds A, C, and D. Data for shroud B are reproduced from figure 4 for comparison and these results are shown in figure 7.

All data were taken when unseparated flow had been established, except in shroud C for which apparently the unseparated-flow condition could not always be realized. It is apparent from the good agreement of the data for shrouds A, B, and D, which have chord lengths of 28.8, 19.2 and 9.6 inches, respectively, that, in the range tested, chord length is not a significant parameter in sound generation. Aerodynamically, however, the shrouds A and B were much more stable and produced a greater thrust than shrouds C and D. Shroud D has fluctuating-flow conditions which cause a thrust variation and this in turn excites axial vibrations of the shroud. These flow fluctuations were such as to prevent the evaluation of shroud thrust at the unseparated-flow condition. In general,

then, it seems that if the shroud is operating at its best aerodynamically, it will also produce the least sound and the sound will not be affected greatly by the shroud dimensions.

Tip clearance.- In order to evaluate the effect of propeller tip clearance on the sound produced by a shroud unit, a series of tests were made using shroud B, in which the propeller blades were progressively shortened. Sound pressures were measured at four points ($\theta = 0^{\circ}$, 45°, 90°, and 120°) and were averaged to give the values plotted for the tip-clearance ratios of figure 8. In addition, the measured power and shroud thrust estimated from pressures measured on the shroud surface are given for each operating condition. As the tip-clearance ratio is increased (that is, the blades are shortened) the shroud thrust drops off rapidly, whereas the sound does not change appreciably for tip-clearance ratios up to about 0.01. At greater tip-clearance ratios the sound pressures increase rapidly and apparently approach those for an unshrouded propeller. A limited number of tests were made with the propeller position adjusted to stations of 48 and 32 percent of the chord to compare with results obtained at the normal 40 percent or minimum section of the shroud. Both of these adjustments involved a change in tip clearance and the results indicated the same trend shown in figure 8.

Tip speed.- Tests in the tip Mach number range 0.45 to 0.73 indicated that the pressure amplitude of the fundamental frequency and second harmonic of a two-blade shrouded propeller increased as the 4.5 power and the 5.5 power of the tip speed, respectively, as shown in figure 9. These results are in agreement with those obtained from similar tests of unshrouded propellers (reference 4) and indicate that the laws relating tip speed and sound pressure are approximately the same for shrouded and unshrouded propellers.

Number of blades.- Rotational-sound data obtained with a two-blade and five-blade shrouded propeller, operating at the same tip speed and power coefficients, are shown in figure 10. Data obtained with the five-blade propeller ($mB = 5$) are consistent with those for the two-blade propeller ($mB = 2$, 4, and 6). As in reference 4, it may be assumed that mB values of 2, 4, 5, and 6 represent the fundamental frequencies of the rotational sound generated by two-, four-, five-, and six-blade propellers. Figure 10 shows, in general, that as the number of blades is increased, the rotational sound is decreased much the same as is indicated in reference 4 for an unshrouded propeller.

Figure 11 shows a comparison of the total sound emission of a two- and a five-blade shrouded propeller at the same tip speed and power coefficient. The sound pressures, except those near the axis of rotation, are reduced for the larger number of blades; however, this reduction is less than the rotational-sound measurements of figure 10 would

indicate. Thus, the data of figures 10 and 11 show that vortex noise is an important part of the total for the five-blade propeller. This finding is in agreement with results of tests on unshrouded multiblade propellers reported in reference 5.

Analysis.- An attempt was made to apply the Gutin analysis (references 5 and 6) in which the noise is divided into its torque and thrust components and is useful in predicting the sound from an unshrouded propeller to the shrouded case. This analysis shows that a decrease in thrust causes a decrease in rotational sound. It was found, however, that the rotational-sound-pressure reductions indicated in figure 6 could not be accounted for by use of this analysis. It is concluded that these sound-pressure reductions are not wholly the result of thrust relief of the propeller.

CONCLUSIONS

Sound-pressure measurements at static conditions of five shrouded-propeller units indicate the following conclusions:

1. Maximum total sound pressures produced by a two-blade shrouded propeller may vary from about one-half to twice as much as those for a two-blade unshrouded propeller depending on the flow conditions inside the shroud. In general, the sound produced is a minimum and has a predominant low-frequency content when the flow at the shroud surface is unseparated. At the separated-flow condition, sound pressures are a maximum, all rotational frequencies are strengthened, and much vortex noise is generated.

2. If shroud parameters such as tip clearance, chord length, and so forth, satisfy the aerodynamic requirements, in general, good sound characteristics will also be obtained. Chord length is not a significant parameter in sound generation.

3. The polar distribution of sound and the sound variation as a function of tip speed are approximately the same as for an unshrouded propeller.

4. An appreciable reduction of the maximum total sound pressures may be achieved by an increase in the number of propeller blades for a given operating condition. As the number of blades is increased, the rotational sound decreases markedly and the vortex noise increases to the extent that it comprises a large part of the total sound.

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2. Krüger, W.: On Wind Tunnel Tests and Computations Concerning the Problem of Shrouded Propellers. NACA TM 1202, 1949.

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5. Hicks, Chester W., and Hubbard, Harvey H.: Comparison of Sound Emission from Two-Blade, Four-Blade, and Seven-Blade Propellers. NACA TN 1354, 1947.

6. Gutin, L.: On the Sound Field of a Rotating Propeller. NACA TM 1195, 1948.

TABLE I.– SHROUD–A SECTION COORDINATES

Airfoil section . . . . NACA 4312 (modified)
Maximum thickness . . . . 12 percent of chord
Leading–edge radius . . . . 0.685 inch
Slope of leading–edge radius 0.26667
Chord length . . . . 28.8 inches

Inner surface				Outer surface			
Station		Ordinate		Station		Ordinate	
Percent chord	Inches	Percent thickness	Inches	Percent chord	Inches	Percent thickness	Inches
0.671	0.193	2.590	0.746	1.829	0.527	–1.938	–0.558
1.748	.503	3.714	1.07	3.252	.937	–2.436	–.702
4.093	1.179	5.305	1.528	5.907	1.701	–2.861	–.824
6.559	1.889	6.457	1.86	8.441	2.431	–2.957	–.852
9.089	2.618	7.348	2.116	10.911	3.142	–2.904	–.836
14.253	4.105	8.601	2.477	15.747	4.535	–2.601	–.749
19.481	5.611	9.389	2.704	20.519	5.909	–2.279	–.656
24.735	7.124	9.849	2.837	25.265	7.276	–2.071	–.596
30.000	8.64	10.000	2.88	30.000	8.64	–2.000	–.576
40.095	11.547	9.724	2.801	39.905	11.493	–1.886	–.543
50.173	14.45	8.967	2.582	49.827	14.350	–1.621	–.467
60.223	17.344	7.826	2.254	59.777	17.216	–1.296	–.373
70.239	20.229	6.349	1.829	69.761	20.091	–.961	–.277
80.213	23.101	4.573	1.317	79.787	22.979	–.655	–.189
90.141	24.961	2.500	.72	88.554	25.504	–.378	–.109
95.085	27.384	1.353	.39	94.915	27.336	–.251	–.072
100.000	28.8	0	-----	100.000	28.8	0	------

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TABLE II.– SHROUD–B SECTION COORDINATES

Airfoil section . . . . NACA 4315 (modified)
Maximum thickness . . . . 15 percent of chord
Leading–edge radius . . . . 0.713 inch
Slope of leading–edge radius 0.26667
Chord length . . . . 19.2 inches

Inner surface				Outer surface			
Station		Ordinate		Station		Ordinate	
Percent chord	Inches	Percent thickness	Inches	Percent chord	Inches	Percent thickness	Inches
0.527	0.101	3.156	0.606	1.973	0.527	–2.504	–0.481
1.560	.300	4.483	.861	3.440	.660	–3.205	–.615
3.866	.742	6.326	1.215	6.134	1.178	–3.882	–.745
6.323	1.214	7.633	1.466	8.677	1.666	–4.133	–.794
8.861	1.701	8.629	1.657	11.139	2.139	–4.185	–.804
14.066	2.701	10.002	1.920	15.934	3.059	–4.002	–.768
19.352	3.716	10.847	2.083	20.648	3.964	–3.737	–.718
24.669	4.736	11.339	2.177	25.331	4.864	–3.561	–.684
30.000	5.76	11.500	2.208	30.000	5.76	–3.500	–.672
40.119	7.703	11.175	2.146	39.881	7.657	–3.337	–.641
50.216	9.641	10.290	1.976	49.784	9.559	–2.944	–.565
60.279	11.574	8.965	1.721	59.721	11.466	–2.435	–.468
70.298	13.497	7.263	1.394	69.702	13.383	–1.875	–.360
80.267	15.411	5.227	1.004	79.733	15.309	–1.309	–.251
90.176	17.314	2.859	.549	89.824	17.246	–.737	–.142
95.106	18.260	1.552	.298	94.894	18.220	–.450	–.086
100.000	19.2	0	-----	100.000	19.2	0	------

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TABLE III.– SHROUD–C SECTION COORDINATES

Airfoil section . . . . NACA 4318 (modified)
Maximum thickness . . . . 18 percent of chord
Leading–edge radius . . . . 0.514 inch
Slope of leading–edge radius 0.26667
Chord length . . . . 9.6 inches

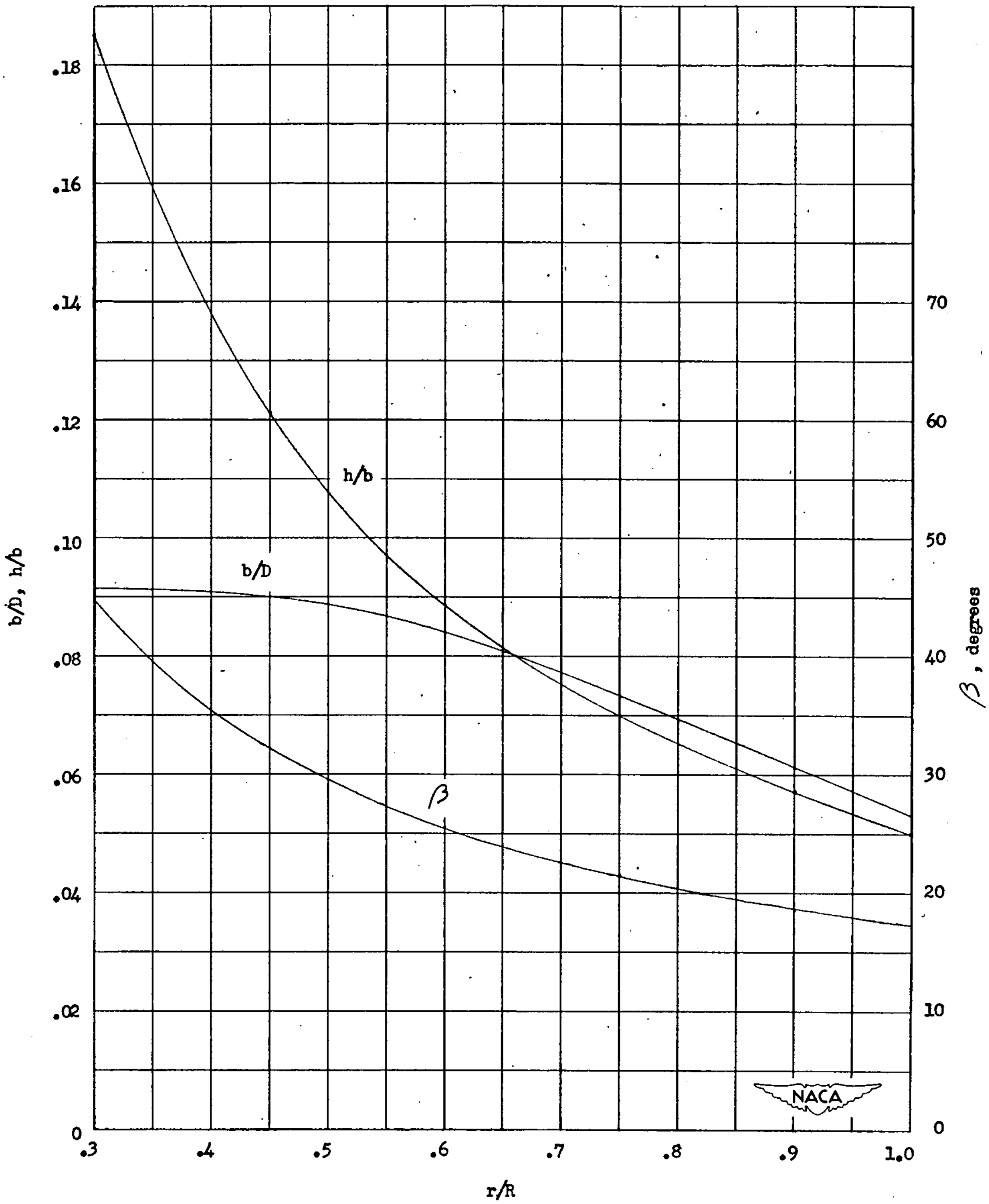
Inner surface				Outer surface			
Station		Ordinate		Station		Ordinate	
Percent chord	Inches	Percent thickness	Inches	Percent chord	Inches	Percent thickness	Inches
0	0	0	0	0	0	0	0
.382	.037	3.723	.357	2.118	.203	–3.071	–.295
1.382	.132	5.252	.504	3.628	.348	–3.974	–.382
3.639	.349	7.347	.705	6.361	.611	–4.903	–.471
6.088	.584	8.810	.846	8.912	.856	–5.310	–.510
8.633	.829	9.910	.951	11.367	1.091	–5.466	–.525
13.880	1.333	11.403	1.095	16.120	1.548	–5.403	–.519
19.222	1.845	12.306	1.181	20.778	1.995	–5.196	–.499
24.603	2.362	12.829	1.232	25.397	2.438	–5.051	–.485
30.000	2.880	13.000	1.248	30.000	2.880	–5.000	–.480
40.142	3.854	12.627	1.212	39.858	3.826	–4.789	–.460
50.259	4.825	11.615	1.115	49.741	4.775	–4.269	–.410
60.335	5.792	10.106	.970	59.665	5.728	–3.576	–.343
70.358	6.754	8.176	.785	69.642	6.686	–2.788	–.268
80.320	7.711	5.880	.565	79.680	7.649	–1.962	–.188
90.211	8.660	3.220	.309	89.789	8.620	–1.098	–.105
95.128	9.132	1.753	.168	94.872	9.108	–.651	–.063
100.000	9.600	0	0	100.000	9.600	0	0

TABLE IV.- SHROUD-D SECTION COORDINATES

Airfoil section . . . . NACA 4318 (modified)
Maximum thickness . . . . 18 percent of chord
Leading-edge radius . . . . 0.713 inch
Slope of leading-edge radius 0.26667
Chord length . . . . 9.6 inches

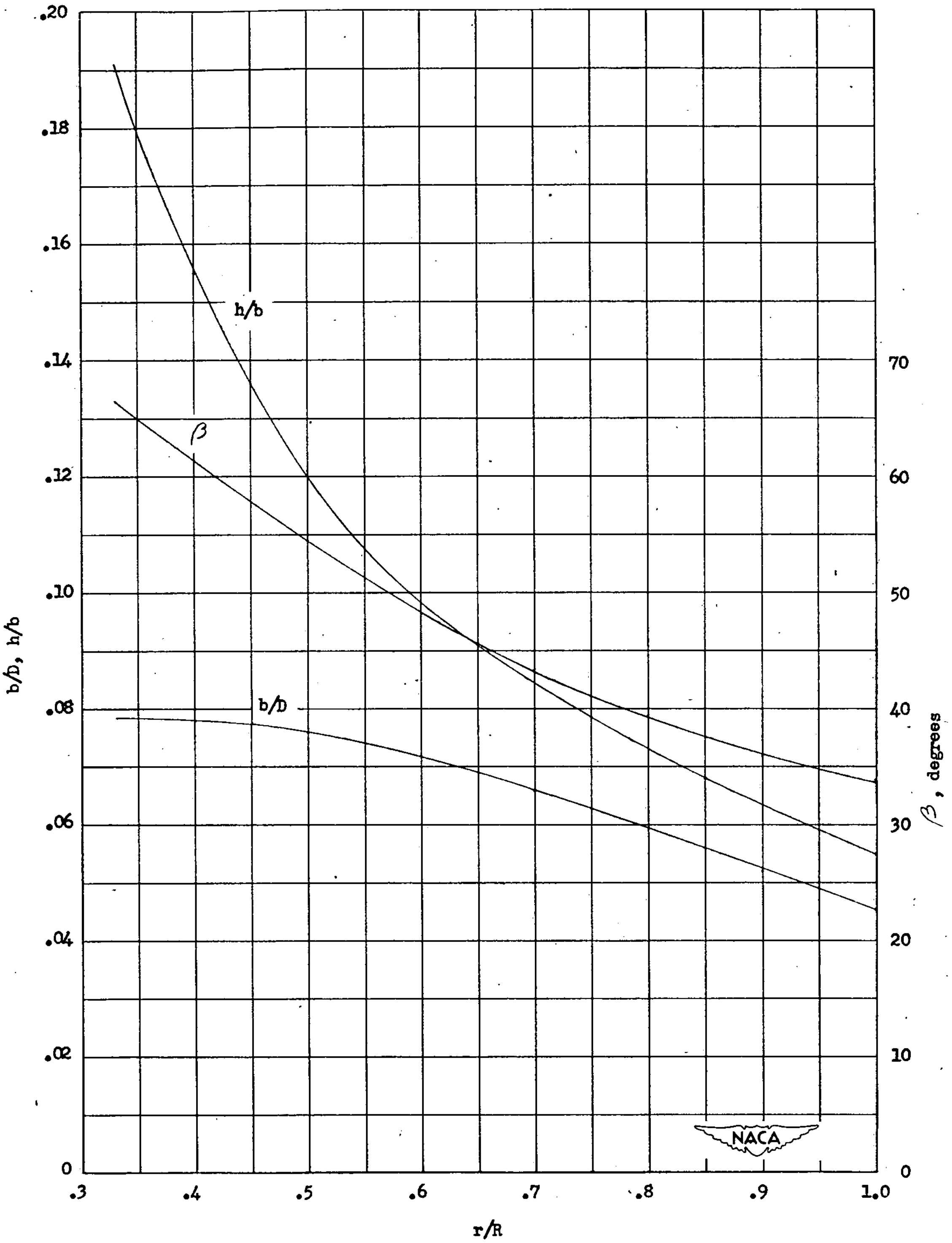
Inner surface				Outer surface			
Station		Ordinate		Station		Ordinate	
Percent chord	Inches	Percent thickness	Inches	Percent chord	Inches	Percent thickness	Inches
0	0	0	0	0	0	0	0
.235	.023	4.297	.413	2.265	.217	-3.645	-.350
1.182	.113	6.030	.579	3.818	.367	-4.752	-.456
3.472	.333	8.103	.778	6.528	.627	-5.659	-.543
5.970	.573	9.396	.902	9.030	.867	-5.896	-.566
8.560	.822	10.323	.991	11.440	1.098	-5.879	-.564
13.859	1.331	11.562	1.111	16.141	1.549	-5.562	-.534
19.217	1.845	12.364	1.188	20.783	1.995	-5.254	-.504
24.603	2.362	12.830	1.232	25.397	2.439	-5.034	-.485
30.000	2.880	13.000	1.248	30.000	2.880	-5.000	-.480
40.142	3.854	12.627	1.212	39.858	3.826	-4.789	-.460
50.259	4.825	11.615	1.115	49.741	4.775	-4.775	-.410
60.335	5.792	10.106	.970	59.665	5.728	-3.576	-.343
70.358	6.754	8.176	.785	69.642	6.686	-2.788	-.268
80.320	7.711	5.880	.565	79.680	7.649	-1.962	-.188
90.211	8.660	3.220	.309	89.789	8.620	-1.098	-.105
95.128	9.132	1.753	.168	94.872	9.108	-.651	-.063
100.000	9.600	0	0	100.000	9.600	0	0

Figure 1.- Two-blade shroud-unit test installation (front view).



(a) Two-blade shrouded propeller.

Figure 2.- Blade-form curves.



(b) Five-blade shrouded propeller.

Figure 2.- Concluded.

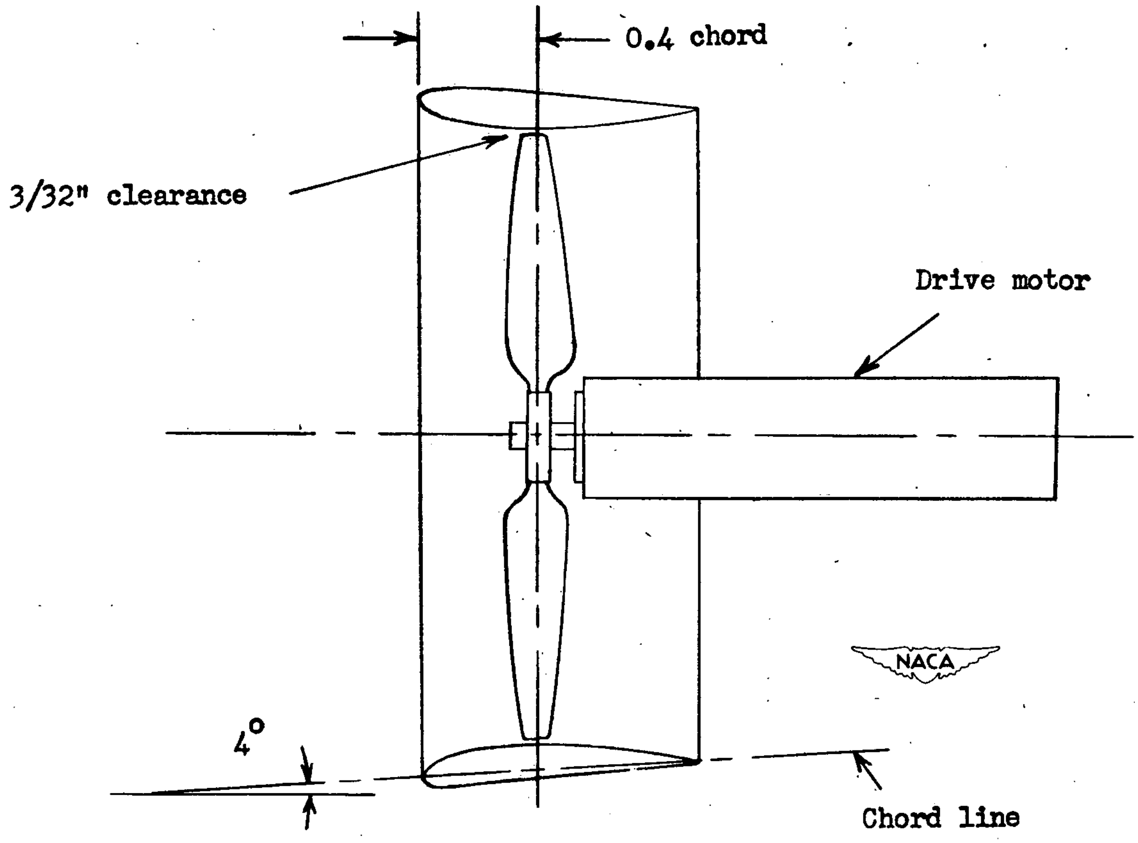


Figure 3.– Schematic view of shrouded-propeller test arrangement.

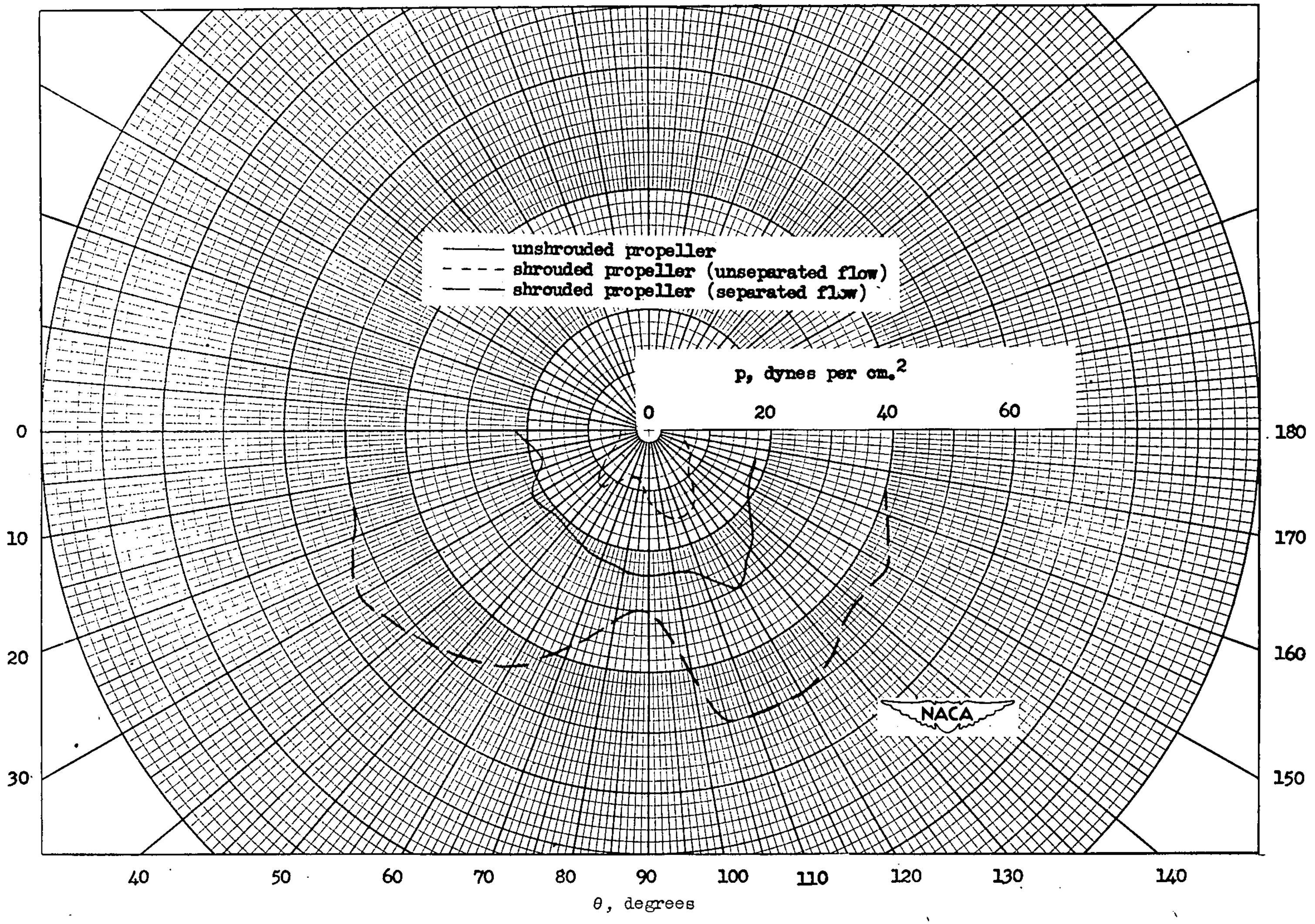


Figure 4.– Polar distribution of total sound produced by a shrouded and an unshrouded propeller at approximately the same tip speed and power. $N = 3300$ rpm; $s = 30$ feet; $P_H = 68$ horsepower.

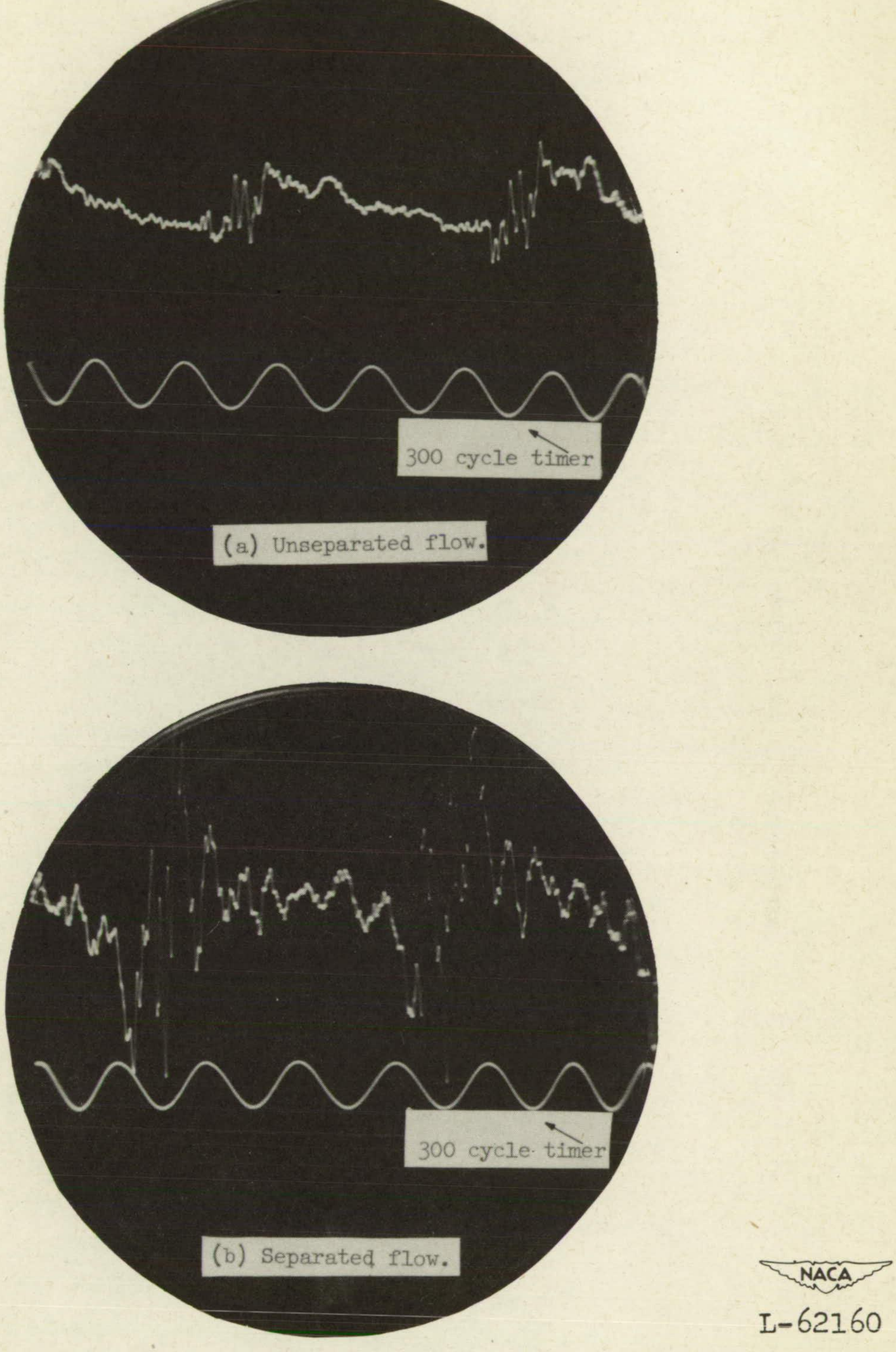
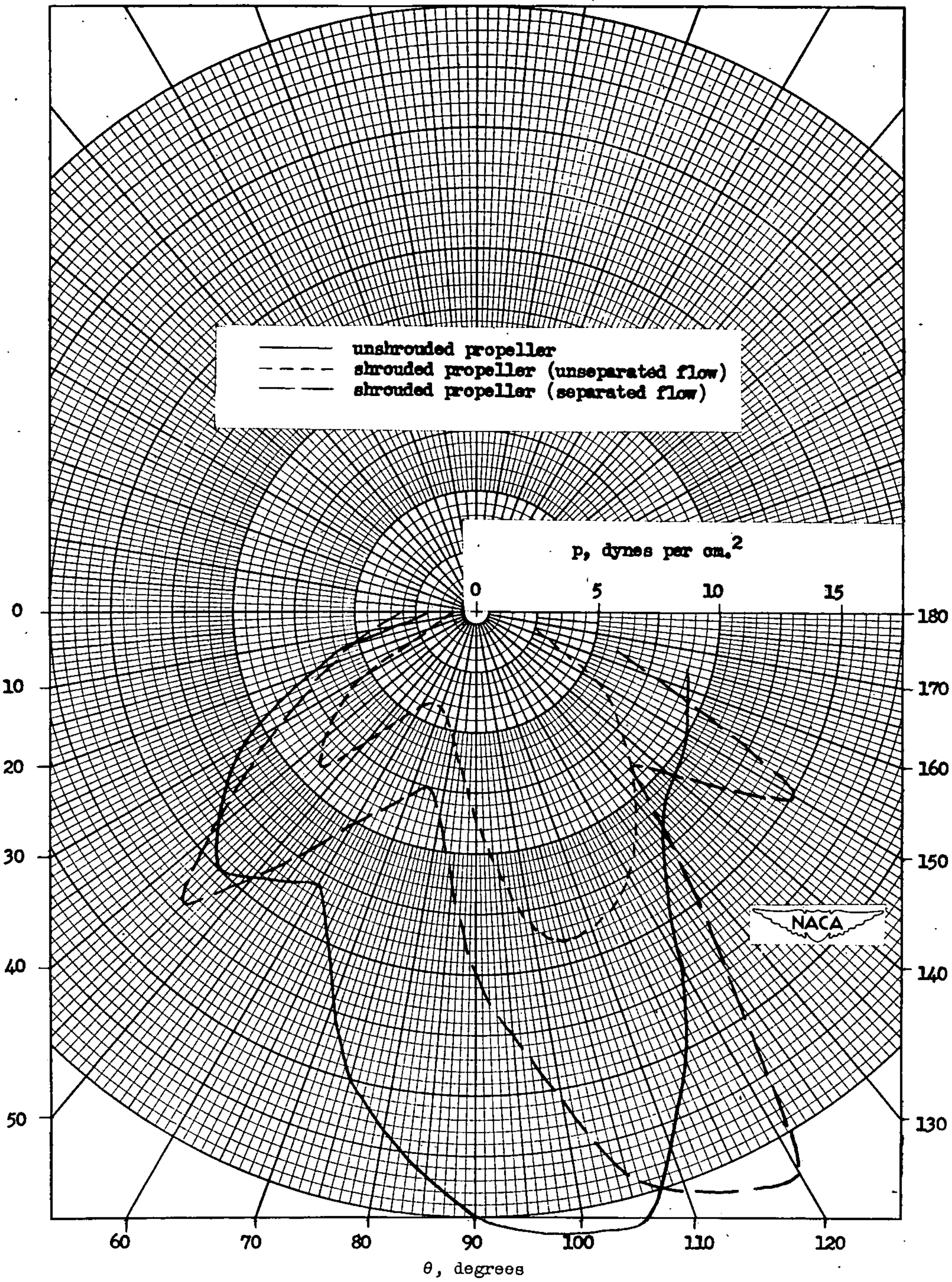
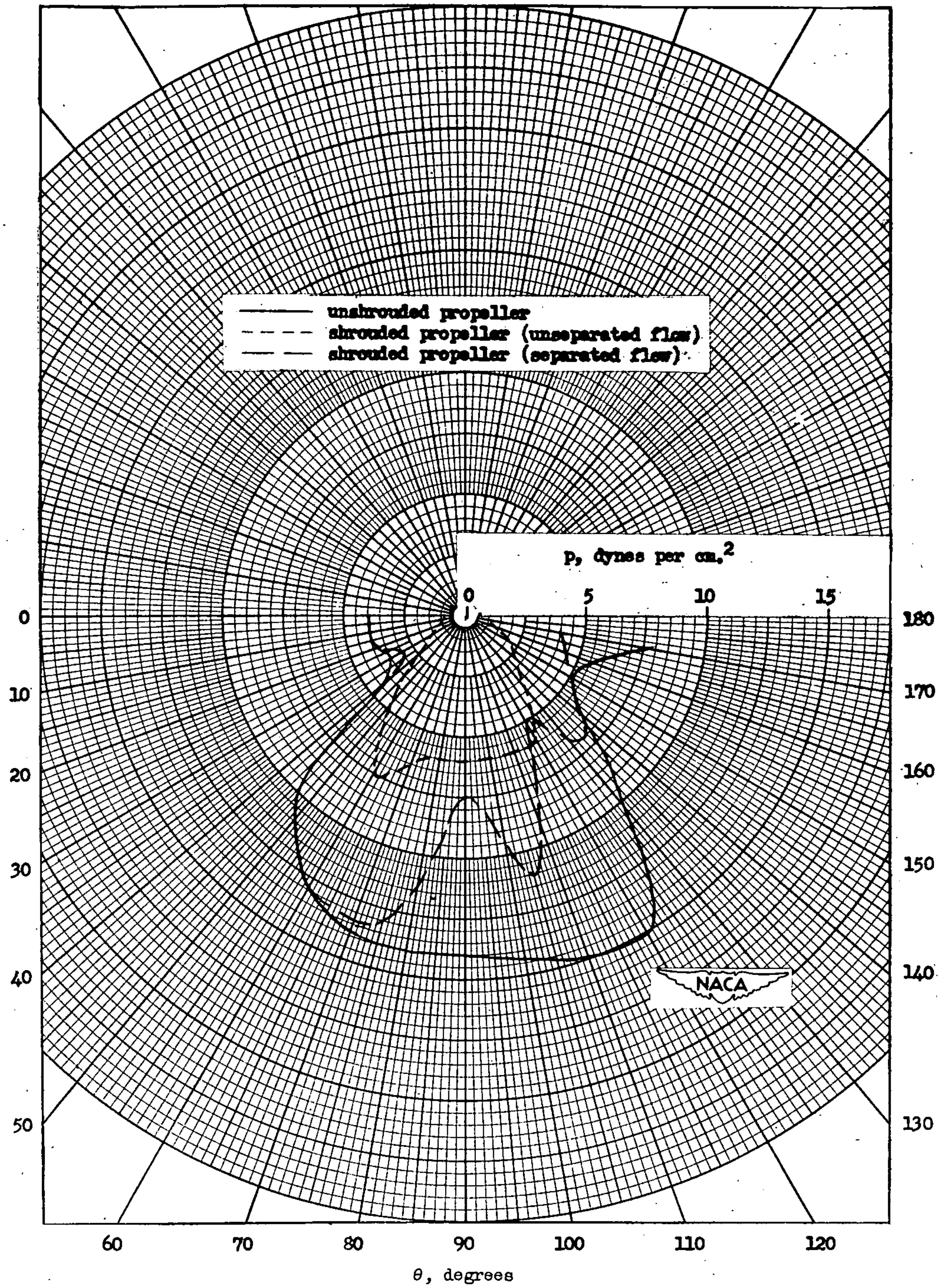


Figure 5.– Oscillograph records of sound emission of a two-blade shrouded propeller for two flow conditions inside the shroud. $\beta = 21.5^{\circ}$; $\theta = 120^{\circ}$; N = 3300 rpm; s = 30 feet.



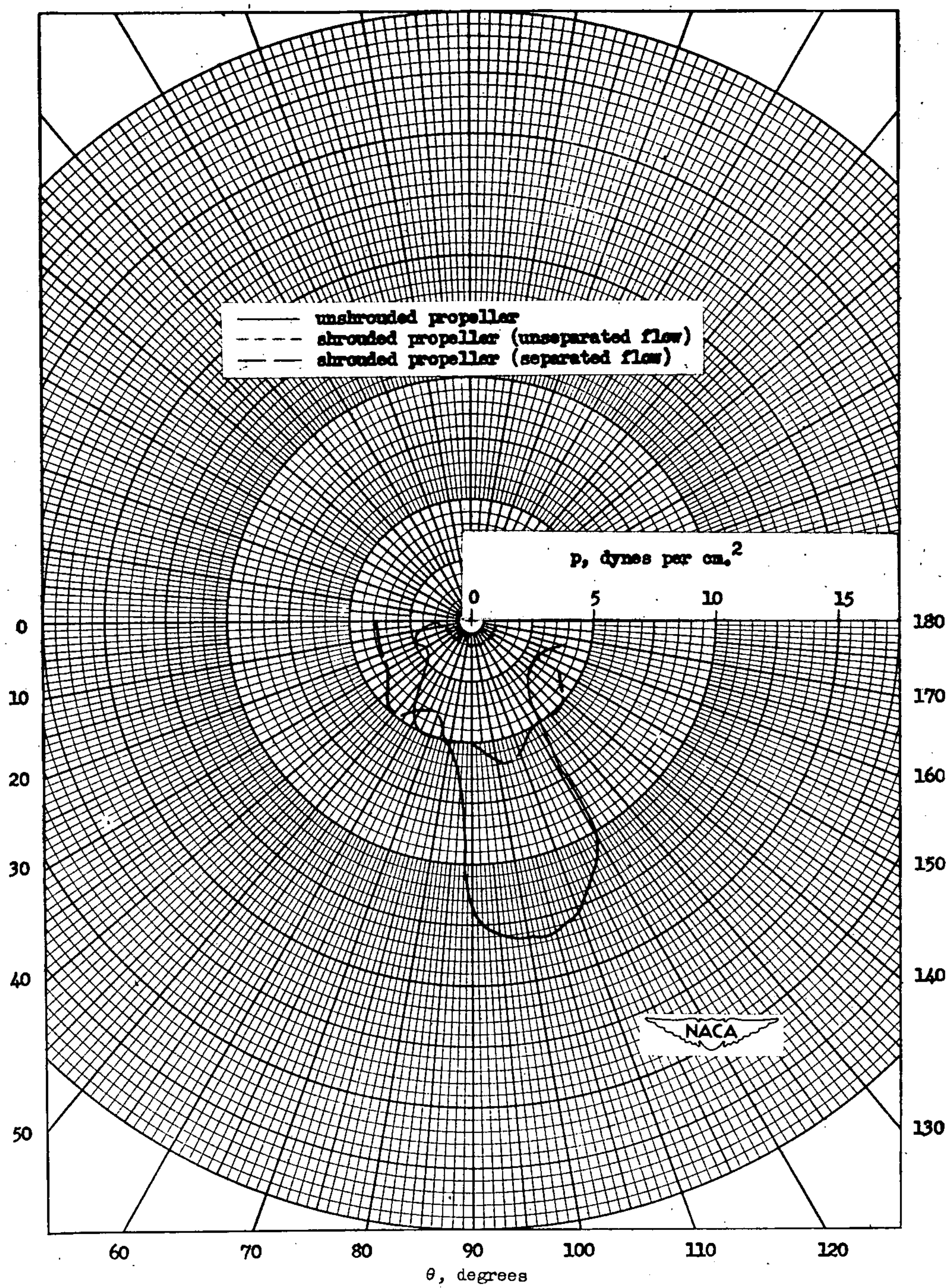
(a) mB = 2.

Figure 6.– Polar distribution of the first four harmonics of sound of a shrouded and an unshrouded propeller at approximately the same rotational speed and power. N = 3300 rpm; P_H = 68 horsepower; s = 30 feet.



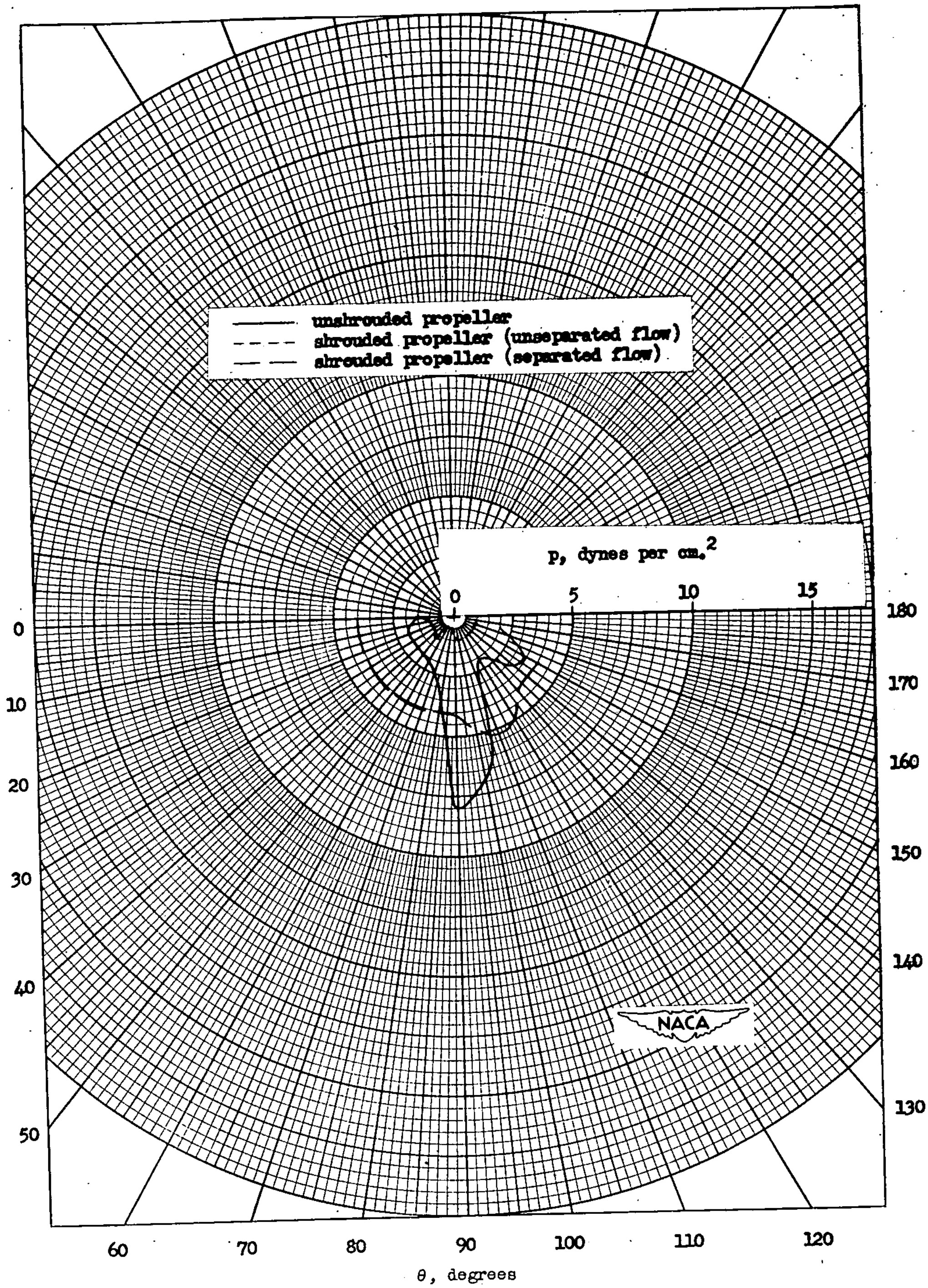
(b) mB = 4.

Figure 6.- Continued.



(c) mB = 6.

Figure 6.– Continued.



(d) mB = 8.

Figure 6.– Concluded.

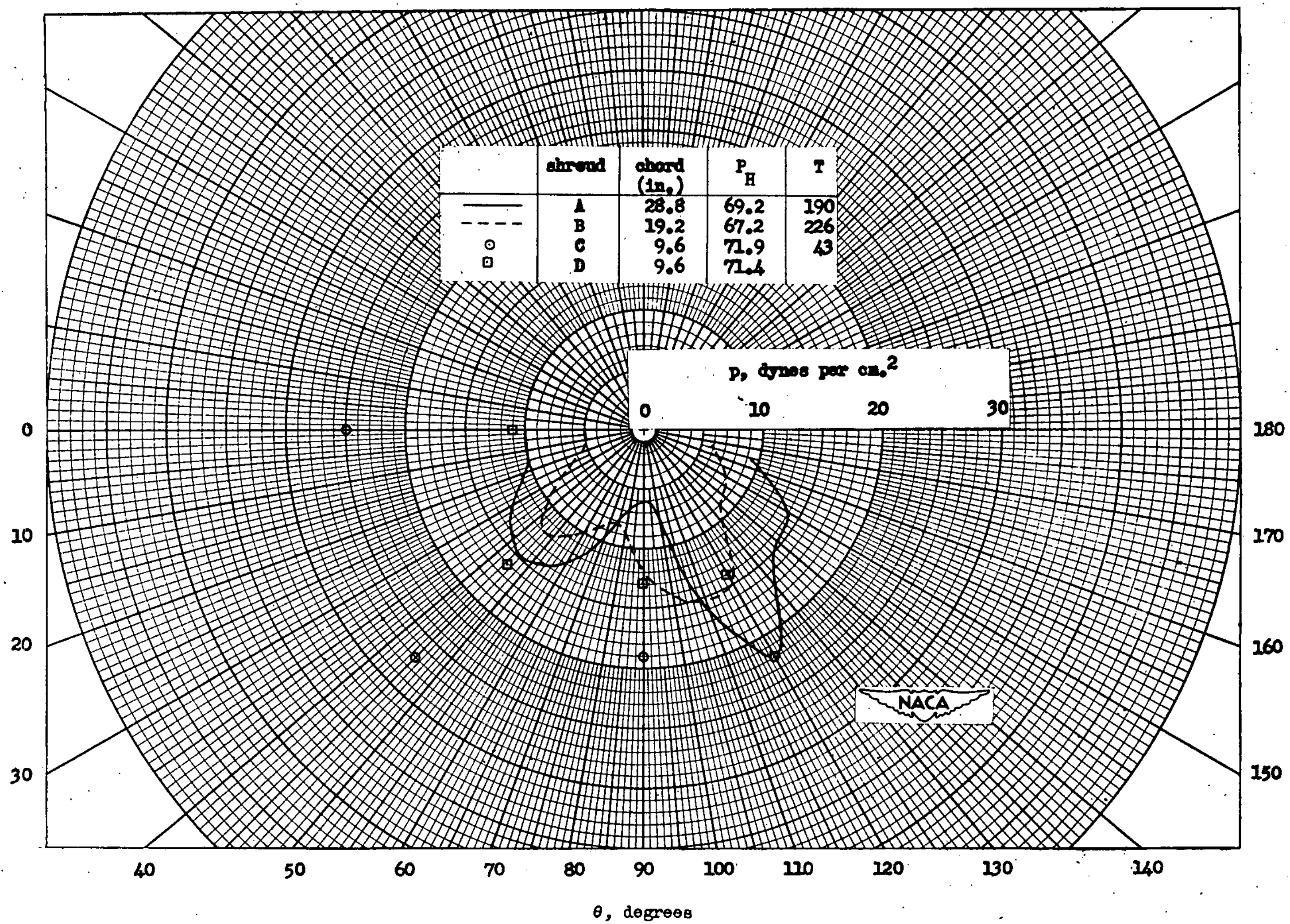


Figure 7.– Comparison of total sound generated by four shroud units. N = 3300 rpm; β = 21.5°; s = 30 feet.

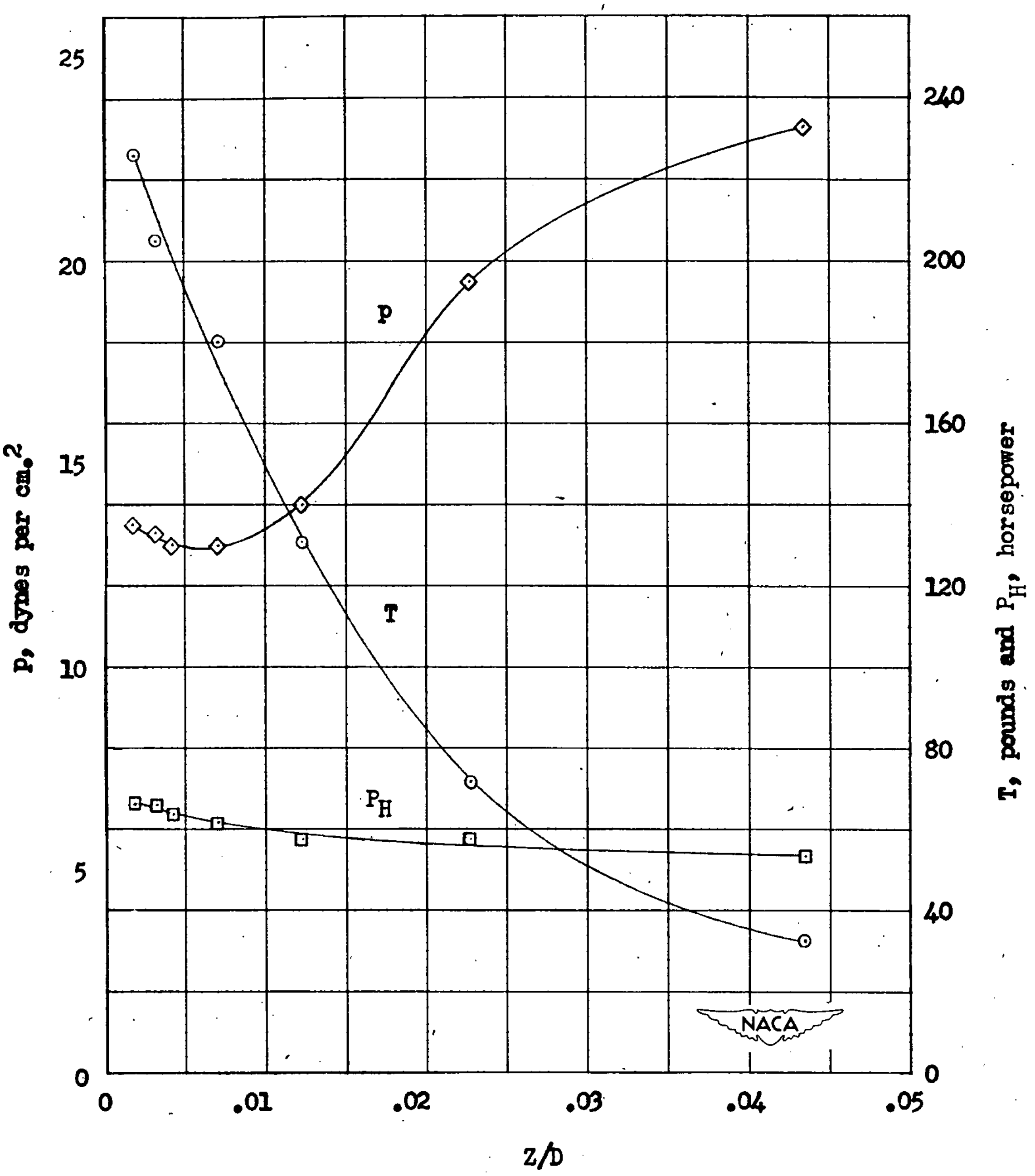


Figure 8.- Effect of tip-clearance ratio on the power absorption, shroud thrust, and sound emission of a shrouded propeller. s = 30 feet; N = 3300 rpm.

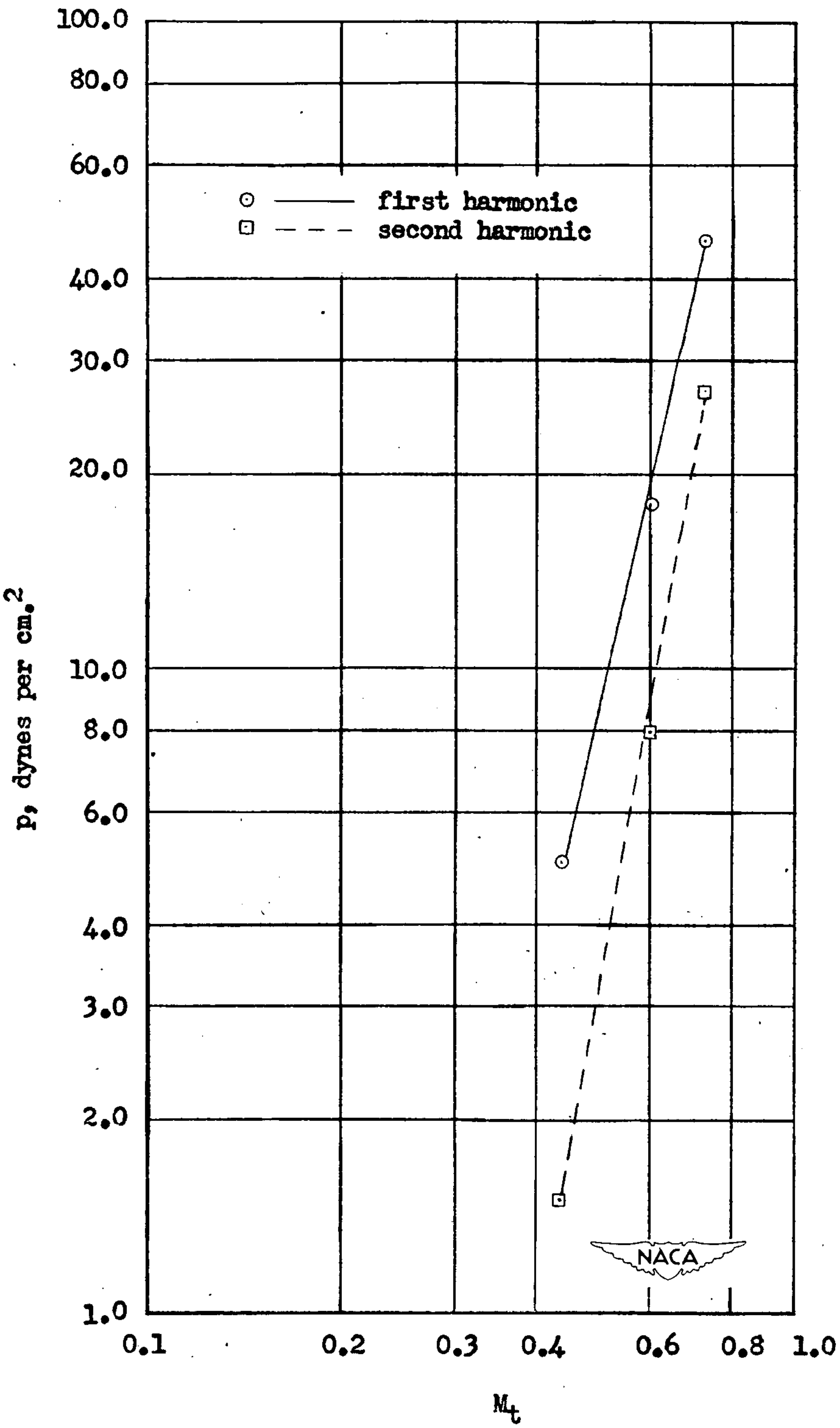


Figure 9.- Variation of pressure amplitude with tip Mach number for the first two harmonics of a two-blade shrouded propeller operating in shroud A. s = 30 feet; $\beta_{0.75}$ = 21.5°; θ = 120°.

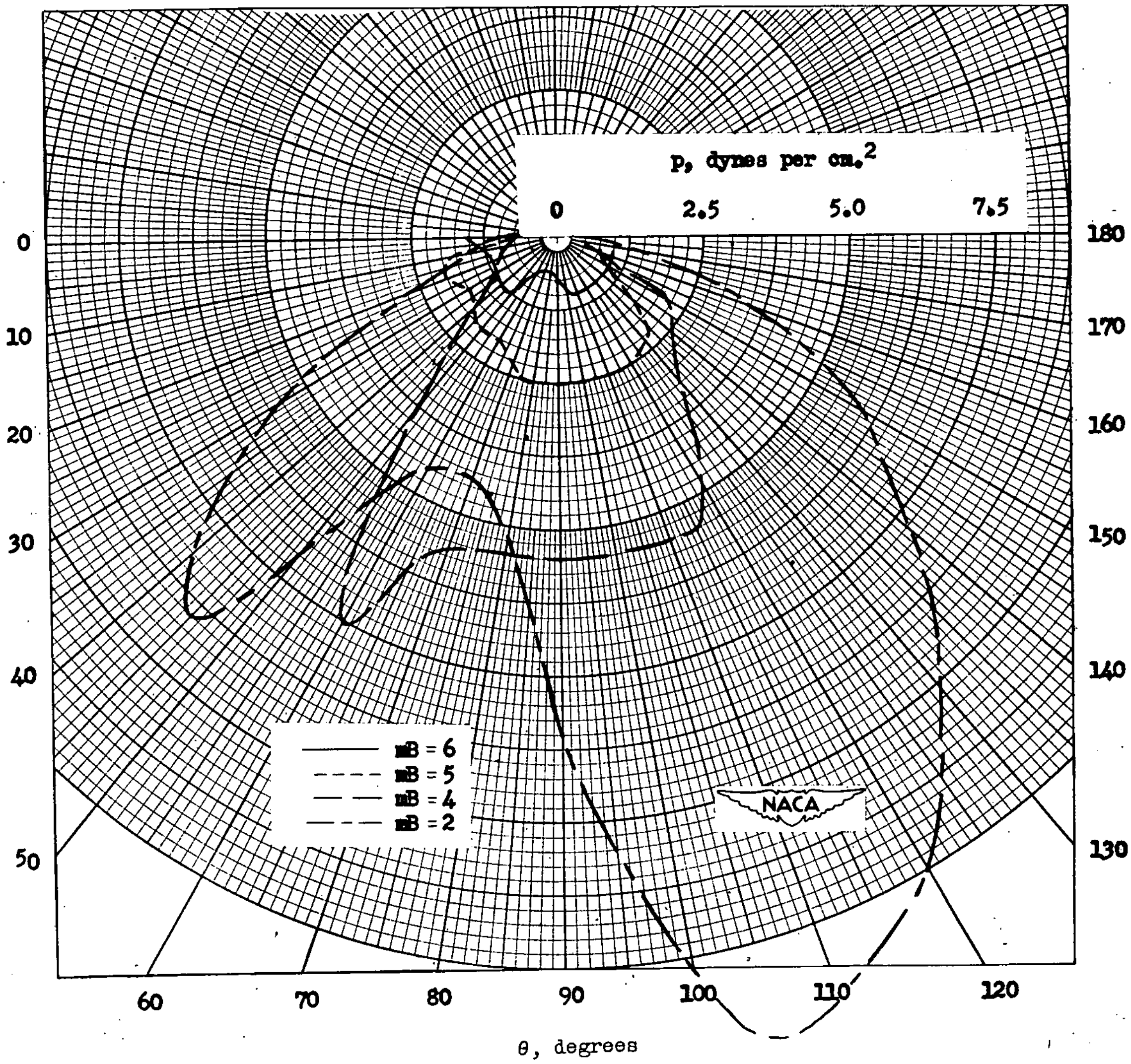


Figure 10.– Effect of number of blades on the rotational-sound emission of a shrouded propeller. N = 3300 rpm; s = 30 feet; P_H = 68 horsepower.

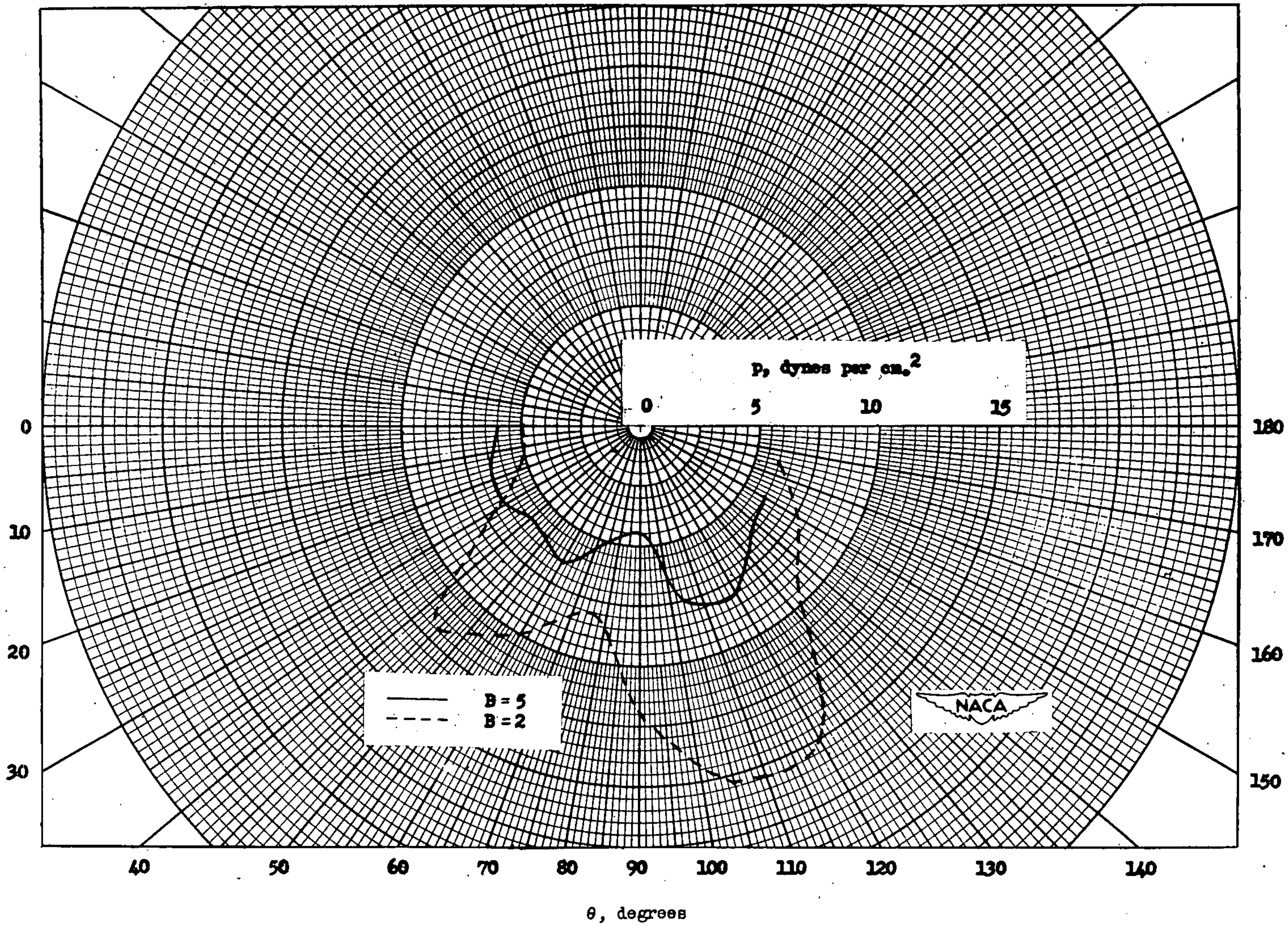


Figure 11.- Comparison of the total sound emission of two- and five-blade shrouded propellers at the same tip speed and power coefficients. $M_t = 0.60$; $s = 30$ feet; $P_H = 68$ horsepower.